A FIBRE REINFORCED METAL ROTOR

The present invention relates to a fibre reinforced metal rotor. The present invention relates particularly to fibre reinforced metal discs and fibre reinforced metal rings which are suitable for use in gas turbine engines as blade carrying compressor, or turbine, rotors. The present invention is particularly suitable for applications where the fibre reinforced metal rotor has a large diameter and is intended to rotate at high speeds.

A conventional compressor rotor for a gas turbine engine comprises a solid unreinforced metal disc which has a relatively large hub, a relatively large rim and a relatively thin diaphragm which extends between the hub and the rim. The rim carries compressor blades which extend radially from the rim. The compressor blades may be integral with the rim or the compressor blades may have roots which are arranged to locate in axially or circumferentially extending grooves in the rim. The compressor blades which are integral with the rim may be friction welded to the rim or may be machined from the forged disc.

It is known to provide a compressor rotor for a gas turbine engine which comprises a solid fibre reinforced metal ring, for example as in UK Patent GB2247492. The ring carries compressor blades which extend radially from the ring. The compressor blades may be integral with the ring or the compressor blades may have roots which are arranged to locate in axially or circumferentially extending grooves in the ring. The compressor blades which are integral with the ring may be friction welded to the ring or may be machined from the ring. This solid fibre reinforced compressor rotor does not have a diaphragm and hub as in the conventional solid metal compressor disc.

It is important in gas turbine engines used on aircraft to minimise the weight of the gas turbine

engine. It is also necessary to increase the thrust of gas turbine engines, and this has necessitated an increase in the size of the gas turbine engine. It has been found that the use of solid fibre reinforced metal rings, about 0.5 metre outer radius, designed to operate at a rotational speed of about 11000 revolutions per minute (rpm) and carrying large, heavy, blades are about 10 percent heavier than a conventional solid metal disc. This is because the fibre reinforced metal ring has to be made massive enough to carry the loads of the blades.

The present invention seeks to provide a solid fibre reinforced metal rotor which has reduced weight compared to the known solid fibre reinforced metal ring and known solid metal disc.

Accordingly the invention provides a fibre reinforced metal rotor comprising a hub, a rim and a member extending radially between and interconnecting the hub and the rim, the fibre reinforced metal disc having an axis of rotation,

the fibre reinforced metal rotor having at least two rings of fibres arranged integrally within the fibre reinforced metal rotor,

a first ring of fibres being arranged substantially at a first radial distance from the axis of rotation , a second ring of fibres being arranged substantially at a second radial distance from the axis of rotation and the second radial distance is greater than the first radial distance,

the first ring of fibres being arranged in the hub of the fibre reinforced metal rotor.

Preferably the second ring of fibres is arranged in the rim.

The fibre reinforced metal rotor may comprise titanium, titanium aluminide, an alloy of titanium, or any suitable metal, alloy or intermetallic which is capable of being bonded.

The reinforcing fibres may be silicon carbide, silicon nitride, boron, alumina or other suitable fibres.

The fibre reinforced metal rotor may have at least one rotor blade. The at least one rotor blade may be integral with the fibre reinforced metal rotor. The at least one rotor blade may have a root arranged to fit in at least one axially, or circumferentially, extending groove in the fibre reinforced metal rotor.

The fibre reinforced metal rotor has an outer radius, the outer radius is at least about 0.5 metres.

The present invention will be more fully described by way of example with reference to the accompanying drawings, in which:-

Figure 1 is a cross-sectional view through a conventional solid unreinforced metal rotor.

Figure 2 is a cross-sectional view through a known fibre reinforced metal rotor.

Figure 3 is a cross-sectional view through a fibre reinforced metal rotor according to the present invention.

Figure 4 is a cross-sectional view through a gas turbine engine showing a fibre reinforced titanium compressor rotor.

Figure 5 is a cross-sectional view through a preform used to make a fibre reinforced metal rotor as shown in figure 3.

Figure 6 is a cross-sectional view through an alternative fibre reinforced metal rotor according to the present invention.

A conventional compressor rotor 10, as shown in figure 1, for a gas turbine engine comprises a solid unreinforced metal disc 12 which has a relatively large hub 14, a relatively large rim 16 and a relatively thin diaphragm 18 which extends between and interconnects the hub 14 and the rim 16. The rim 16 carries compressor rotor blades 20 which extend radially from the rim 16. The compressor rotor blades 20 may be integral with the rim 16 or the compressor rotor blades 20 may have roots which are arranged to locate in axially or circumferentially extending grooves, not shown, in the rim 16. The compressor rotor blades 20 which are

integral with the rim 16 may be friction welded to the rim 16 or may be machined from the forged disc.

Another known compressor rotor 30, as shown in figure 2, for a gas turbine engine comprises a ceramic fibre reinforced metal ring 32. The ring 32 carries compressor rotor blades 34 which extend radially from the ring 32. The ring 32 comprises a ring of fibres 36, the individual ceramic fibres 38 extending circumferentially through 360 degrees. The compressor rotor blades 34 may be integral with the ring 32 or the compressor rotor blades 34 may have roots which are arranged to locate in axially or circumferentially extending grooves in the ring 32. The compressor blades which are integral with the ring 32 may be friction welded to the ring 32 or may be machined from the ring 32.

It is to be noted that the ceramic fibre reinforced compressor rotor 30 does not have a diaphragm and hub as in the conventional solid metal compressor disc 10. The ring of fibres 38 increases the hoop strength of the ring 32 and the ceramic fibres 38 reduce the density of the ring 32. The volume fraction of fibres in the ring of fibres 38 is about 30 percent.

As an example a ceramic fibre reinforced compressor rotor 30 with an outer radius of 0.5 metres, or greater, carrying large, heavy, compressor blades and arranged to operate at about 11000 revolutions per minute (rpm) is heavier than a conventional solid metal compressor rotor 10 with the same diameter. This is because the free ring radius, the radius beyond which the material of the rotor is not load bearing, decreases with increasing speed of rotation. The free ring radius for a ceramic fibre reinforced ring 32 operating at 11000 rpm is very close to the outer radius of the ceramic fibre reinforced ring 32. Therefore the ceramic fibre reinforced metal ring 32 has to be more massive to carry the loads of the compressor blades 34. The introduction of the ceramic fibres 38 reduces the density of the ring 32, but does not reduce the weight of the

ring 32 to less than that of the ring 10, because the mass of the ring 32 is concentrated substantially at the radius of attachment of the blades 34 to the ring 32.

However, the free ring radius decreases with increasing speed and decreases with increasing blade loading. The free ring radius is also dependent upon the metal and the fibres. The free ring radius for a fibre reinforced metal is greater than that for an unreinforced metal. Thus a ceramic fibre reinforced compressor rotor 32 with an outer diameter less than 0.5 metres may be heavier than a conventional solid metal compressor rotor 10, of the same diameter, if the speed of rotation and or blade loads are sufficiently high.

A compressor rotor 40 according to the present invention, as shown in figure 3, for a gas turbine engine comprises a ceramic fibre reinforced metal disc 42 which has a relatively large hub 44, a relatively large rim 46 and a relatively thin diaphragm 48 which extends between and interconnects the hub 44 and the rim 46. The rim 46 carries compressor rotor blades 50 which extend radially from the rim 46. The compressor rotor blades 50 may be integral with the rim 46 or the compressor rotor blades 50 may have roots which are arranged to locate in axially or circumferentially extending grooves, not shown, in the rim 46. The compressor rotor blades 50 which are integral with the rim 46 may be friction welded to the rim 46 or may be machined from the disc 42.

The disc 42 comprises a first ring of fibres 52, the individual ceramic fibres 54 extending circumferentially through 360 degrees. The first ring of fibres 52 is arranged substantially at a first radial distance R_1 from the axis of rotation X of the disc 42 and the first ring of fibres 52 is coaxial with the axis of rotation X. The disc 42 comprises a second ring of fibres 56, the individual ceramic fibres 58 extending circumferentially through 360 degrees. The second ring of fibres 56 is arranged substantially at a second radial distance R_2 from the axis of rotation X and the second

ring of fibres 56 is coaxial with the axis of rotation X. The second radial distance R_2 is greater than the first radial distance R_1. In this example the first ring of fibres 52 is arranged in the hub 44 of the disc 42 and the second ring of fibres 56 is arranged in the rim 46 of the disc 42. The volume fraction of fibres in the rings of fibres 52 and 56 is about 30 percent, but other volume fractions may be used.

The second ring of fibres 56 is introduced into the rim 46 of the disc 42 to reduce the density of the rim 44 and hence its weight, but the second ring of fibres 56 is designed to be insufficient on its own to carry the load of the compressor rotor blades 50. The second ring of fibres 56 also reduces the load carrying requirement of the hub 44 of the disc 42 and thus enables the hub 44 to be made smaller. The first ring of fibres 52 is introduced into the hub 44 of the disc 42 to carry the loads on the compressor rotor blades 50 and reduces the density of the hub 44 and hence its weight. The result of using the ceramic fibre reinforcement at the hub 44 and rim 46 of the disc 42 is that both the hub 44 and the rim 46 of the disc are reduced in size, density and weight compared to the conventional solid metal disc.

As an example a ceramic fibre reinforced titanium disc 42 with an outer radius of about 0.5 metres or greater, carrying large, heavy, compressor blades and arranged to operate at about 11000 revolutions per minute (rpm) has a 26 percent reduction in weight compared to the conventional solid titanium metal disc 12, and a 34 percent reduction in weight compared to a ceramic fibre reinforced titanium ring 32.

However, because the free ring radius decreases with increasing speed and decreases with increasing blade loading the ceramic fibre reinforced compressor rotor 40 with a smaller outer diameter than 0.5 metres may be lighter than a conventional solid metal compressor rotor 10, of the same

diameter, if the speed of rotation and or blade loads are sufficiently high.

A turbofan gas turbine engine 90, as shown in figure 4, comprises in axial flow series an inlet 92 a fan section 94, a compressor section 96, a combustion section 98, a turbine section 100 and an exhaust 102. The compressor section comprises one or more fibre reinforced discs 42 as described with reference to figure 3.

A fibre reinforced metal rotor 42 as shown in figure 3 is manufactured using preforms as shown in figure 5. A first metal ring 112, or metal disc, is formed and a first annular axially extending groove 114 and a second annular axially extending groove 116 are machined in one axial face 118 of the first metal ring 112. The first and second annular grooves 114 and 116 are arranged at radial distances of R_1 and R_2 respectively from the axis X of the metal ring 112. The annular grooves 114 and 116 have parallel straight sides which form a rectangular rectangular cross-section. A second metal ring 120, or metal disc, is formed and a first annular axially extending projection 122 and a second annular axially extending projection 124 are machined from the second metal ring 120 such they extend from one axial face 126 of the second metal ring 120. The second metal ring 120 is also machined to form four annular grooves 128, 130, 132 and 134 in the face 126 of the second metal ring 120. The grooves 128 and 130 are arranged radially on either side of the first annular projection 122 and the grooves 132 and 134 are arranged radially on either side of the second annular projection 124. The grooves 128, 130, 132 and 134 taper from the axial face 126 to the bases of the annular projections 122 and 124.

Circumferentially extending fibres 56 and 54 are arranged in the first and second annular grooves 114 and 116 respectively. The fibres 54 and 56 may be one or more annular fibre preforms, each annular fibre preform comprising a metal coated fibre which is wound into a planar spiral. A

sufficient number of fibres, or annular fibre preforms, are stacked in the annular grooves 114 and 116 to partially fill the annular grooves 114 and 116 to predetermined levels.

The second metal ring 120 is then arranged such that the axial face 126 confronts the axial face 118 of the first metal ring 112, and the axes of the first and second metal rings 112 and 120 are aligned such that the first and second annular projections 122 and 124 on the second metal ring align with the first and second annular grooves 114 and 116 respectively of the first metal ring 112. The second metal ring 120 is then pushed towards the first metal ring 112 such that the first annular projection 122 enters the first annular groove 114 and the second annular projection 124 enters the second annular groove 116. The second metal ring 120 is further pushed until the axial face 126 of the second metal ring 120 abuts the axial face 118 of the first metal ring 112. The grooves 128, 130, 132 and 134 then form annular chambers between the confronting faces 118 and 126 of the first and second metal rings 112 and 120.

The radially inner and outer peripheries of the axial face 118 of the first metal ring 112 are sealed to the radially inner and outer peripheries respectively of the axial face 126 of the second metal ring 120 to form a sealed assembly. The sealing is performed by TIG welding, electron beam welding, laser welding or other suitable welding process to form outer and inner weld seals 136 and 138 respectively.

The second metal ring is provided with pipes 140 and 142 which extend through holes in the second metal ring 120 and which interconnect to the annular grooves 128 and 132 respectively. The annular projections 122 and 124 are provided with axially extending slots.

The pipes 140 and 142 are connected to vacuum pumps and the sealed assembly is evacuated. The sealed assembly is heated to evaporate any glue used to hold the fibre preforms in place, and the evaporated glue passes along the slots on the annular projections 122 and 124 into the annular grooves

128 and 132 and through the pipes 140 and 142. The annular projections prevents movement of the metal coated fibres once the glue has been removed.

The sealed assembly is then heated to diffusion bonding temperature and isostatic pressure is applied to the sealed assembly, this is known as hot isostatic pressing, and this results in axial consolidation of the fibres and diffusion bonding of the first metal ring 112 to the second metal ring 120 and diffusion bonding of the metal on the metal coated fibres to the metal on other fibres and to the first and second metal rings 112 and 120. Following hot isostatic pressing the resulting consolidated and diffusion bonded fibre reinforced metal component is machined to produce the shape of the fibre reinforced metal disc 42. This may involve machining blades from the component, or friction welding blades onto the component or machining axially or circumferentially extending slots to receive blade roots.

It is to be noted that the ceramic fibres are integrally formed into the disc by the consolidation and diffusion bonding process.

This method of manufacture is disclosed more fully in our UK patent application No. 9619890.8 filed 24 September 1996, and this should be consulted for more details.

A compressor rotor 150 according to the present invention, as shown in figure 6, comprises a plurality of compressor discs, in this example a first, upstream, compressor disc 42A and a second, downstream, compressor disc 42B. The compressor discs 42A and 42B are spaced apart by an annular spacer 152 which extends axially between and is secured to the compressor discs 42A and 42B. The rim of the compressor disc 42A carries a plurality of equi-circumferentially spaced radially extending compressor rotor blades 50A. The rim of the compressor disc 42B carries a plurality of equi-circumferentially spaced radially extending compressor rotor blades 50B. The compressor rotor blades 50A and 50B may be integral with the rim 46 or the compressor

blades may have roots which are arranged to locate in axially or circumferentially extending grooves, not show, in the rim 46 of the compressor discs 42A and 42B. The compressor rotor blades 50A and 50B which are integral with the rim 46 may be friction welded to the rim or may be machined from the forged disc.

The compressor discs 42A and 42B and the compressor rotor blades 50A and 50B are designed to lie in radial planes A relative to the axis of rotation x of the compressor rotor 40.

A compressor casing 154 surrounds the compressor rotor 150 and the compressor casing 154 is spaced radially from the tips of the compressor rotor blades 50A and 50B by clearances 156 and 158 respectively. The annular spacer 152 has a plurality of circumferentially and radially extending ribs 160. The compressor casing 154 carries a plurality of stator vane assemblies, only one stator vane assembly is shown. Each stator vane assembly comprises a plurality of equi-circumferentially spaced stator vanes 162 and the radially inner shrouds 164 of the stator vanes 162 cooperate with the ribs 160 on the annular spacer 152 to form a labyrinth seal. The ribs 160 are spaced from the inner shrouds 164 by a clearance 166. The inner shrouds 164 usually comprise a honeycomb or abradable material which is in proximity to the ribs 160.

The annular spacer 152 has a ring of fibres 174 to reinforce the annular spacer 152. The fibres are ceramic fibres and extend circumferentially through 360°. This results in an increase in the stiffness of the annular spacer 152. The stiffness of the annular spacer 152 is controlled by the amount of reinforcing fibres in the ring of fibres 174, the size and the position of the ring of fibres 174 within the annular spacer 152. The ring of fibres 174 is selected to minimise the amount of radial movement, or radial bowing, of the annular spacer 152 relative to the compressor discs 42A and 42B in operation, and preferably the ring of

fibres 174 is selected such that there is no radial movement of the annular spacer 152 relative to the compressor discs 42A and 42B. This is achieved by selecting the ring of fibres 174 so that the radial movement of the annular spacer 152 matches the radial movement of the compressor discs 42A and 42B.

In operation the annular spacer 152 minimises the amount of movement of the radially outer tips 168 of the compressor blades 50B in a radially downstream direction relative to the radially inner ends of the compressor blades 50B. This minimises the movement of the leading edges 170 of the radially outer tips 168 of the compressor blades 50B radially outwardly and minimises the movement of the trailing edges 172 of the radially outer tips 168 of the compressor blades 50B radially inwardly. This minimises the possibility of rubbing between the leading edges of the radially outer tips 168 of the compressor blades 50B and the compressor casing 154 particularly at high operating speeds, and hence minimises the possibility of forming trenches and hence maintains the clearance 158 closer to the designed clearance. Thus the efficiency of the compressor and hence the efficiency of the gas turbine engine is maintained.

Also the spacer 152 minimises the amount of radial movement of the ribs 160 on the annular spacer 152 relative to the inner shrouds 164 of the stator vanes 162. This minimises the possibility of rubbing between the ribs 160 and the inner shrouds 164 of the stator vanes 162 particularly at high operating speeds, and hence minimises the possibility of wearing trenches in the honeycomb or abradable material or wearing the ribs 160. Furthermore this maintains the clearance 166 closer to the designed clearance and thus the efficiency of the compressor and hence the efficiency of the gas turbine engine is maintaned.

Additionally fouling between the trailing edges 172 of the compressor blades 50B and an adjacent stage of stator vanes is prevented. Furthermore, the use of the ring of

fibres 174 in the annular spacer 152 results in the compressor discs 42A and 42B having reduced weight because the discs do not require additional material to give some radial movement control to the annular spacer 152.

In this example the first upstream, compressor disc 42A is a solid metal disc, but the second compressor disc 42B is a fibre reinforced metal disc and comprises a first ring of fibres 74 and a second ring of fibres 76. The first ring of fibres 74 is arranged at a first radial distance from the axis of rotation x in the hub 78 of the disc 44 and the second ring of fibres 76 is arranged at a second radial distance from the axis of rotation x in the rim 80 of the disc 44. The hub 78 and rim 80 are interconnected by a diaphragm 82. The first and second rings of fibres 74 and 76 minimise the weight of the compressor disc 44. The fibres are ceramic fibres and extend circumferentially through 360°.

The metal disc may comprise titanium, titanium aluminide, an alloy of titanium, or any suitable metal, alloy or intermetallic which is capable of being bonded.

The hoop strength of the rings of fibres may be varied by varying the volume fraction of the fibres in the rings of fibres, however 35% is normally used, volume fractions above 35% produce reduced transverse strength.

Although the invention has referred to compressor rotors and discs, the invention is equally applicable to gas turbine engine turbine rotors and discs. The invention is also applicable to other rotors or discs, for example steam turbines etc. The invention is particularly suitable for applications where the fibre reinforced metal rotor has a large diameter and is intended to rotate at high speeds, however the invention is also suitable for other circumstances.